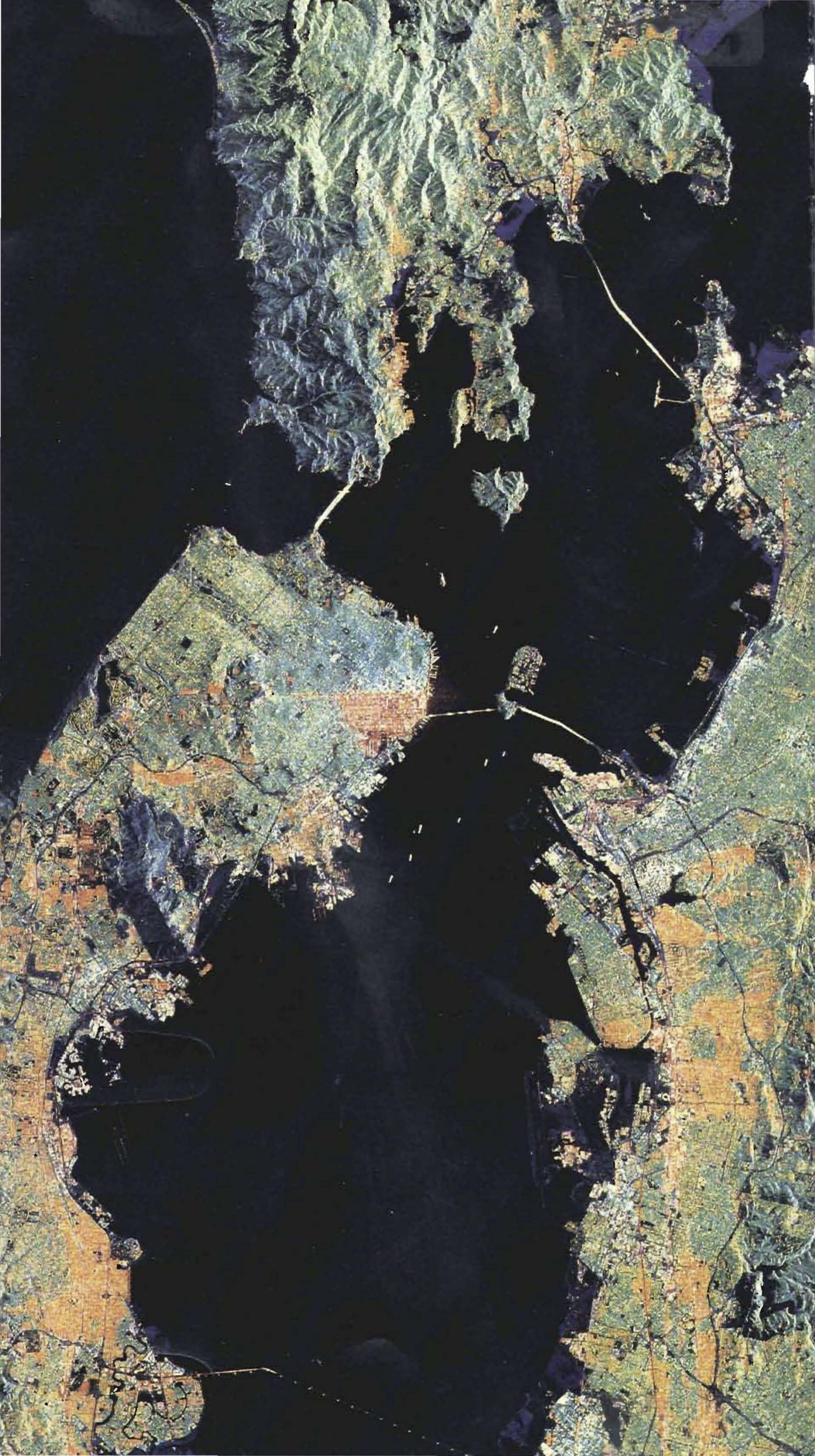


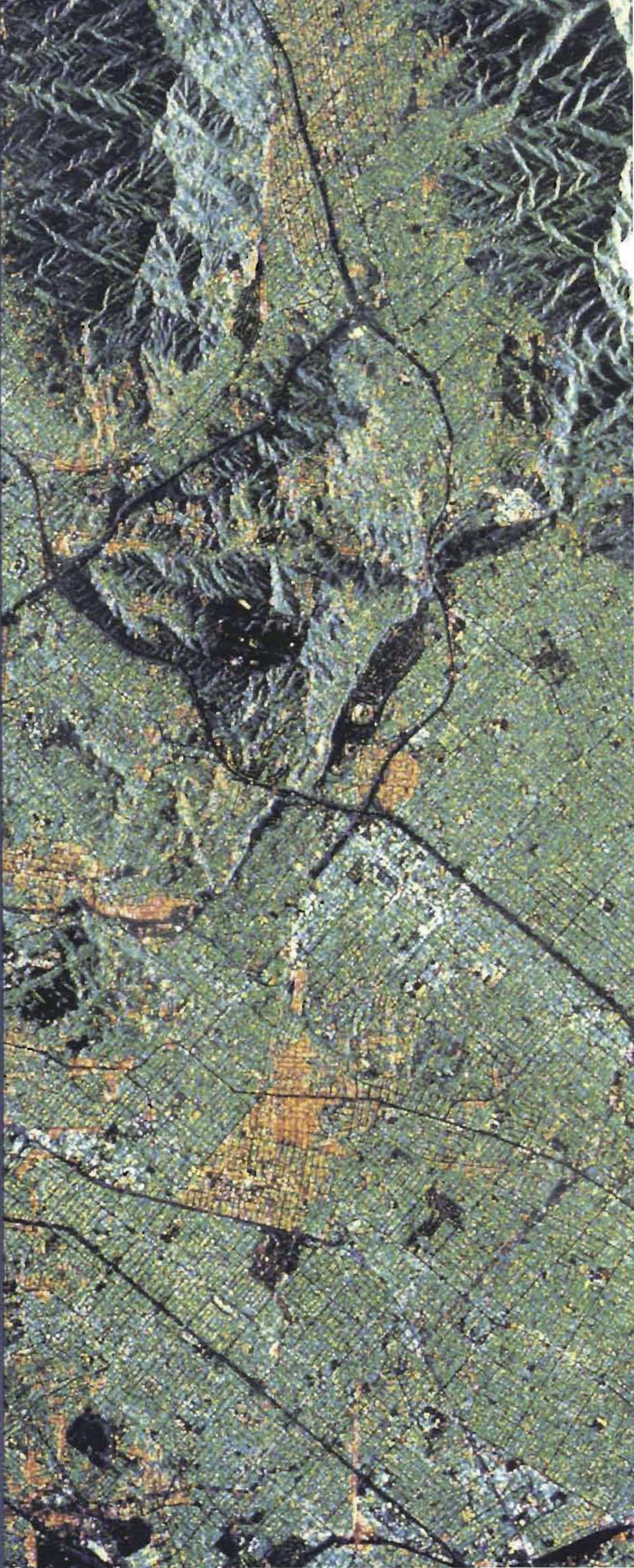
Annual Report

1994

Jet Propulsion Laboratory

About the images

On the orbiting space shuttle, the Spaceborne Imaging Radar–C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) captures San Francisco (cover) and Pasadena (right), California. Pasadena is the home of the Jet Propulsion Laboratory, which spearheads the nation's automated exploration of space. In the two images, the colors represent different frequencies used by the space radar.



Funding for this publication was provided by the California Institute of Technology.

Annual Report

1994

CONTENTS

A description of work accomplished under contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 through December 31, 1994.

JET
PROPULSION
LABORATORY

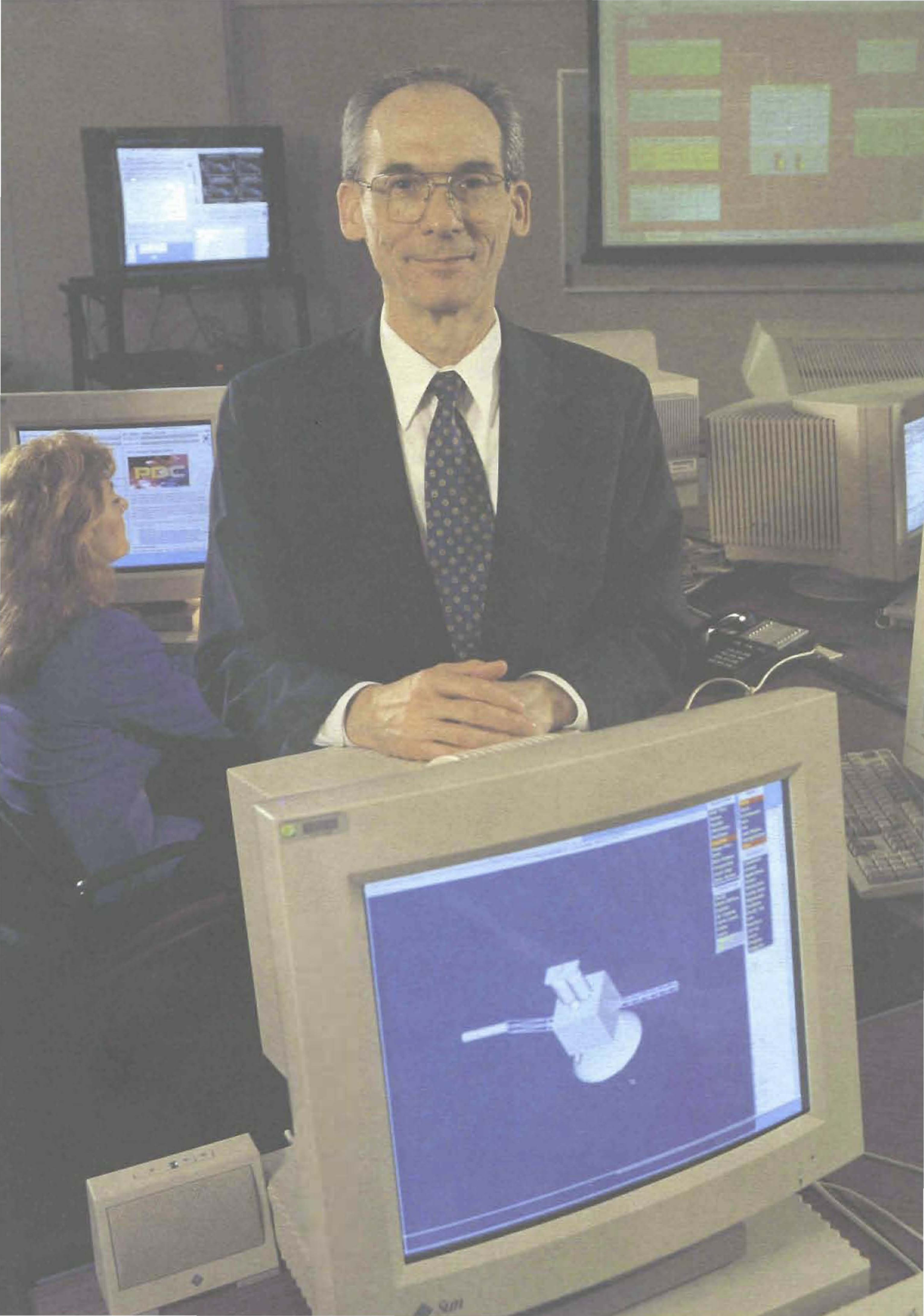
Director's Message

During 1994, the Jet Propulsion Laboratory (JPL) had many significant accomplishments, including a number of important discoveries by JPL-managed projects. The TOPEX/Poseidon oceanographic research satellite, for example, deepened the scientific understanding of the El Niño disturbance in the Pacific Ocean; the Ulysses spacecraft found some unexpected phenomena at the Sun's south polar region, the second Wide Field/Planetary Camera on the Hubble Space Telescope yielded a rich bounty of new astronomical/astrophysical findings, and the Galileo spacecraft made history with its observations of comet Shoemaker–Levy 9's fiery collision with Jupiter.

The past year was also a time of profound change, as the Laboratory continued to adapt itself to the new international, national and budgetary environments of the mid-1990s. No organization survives today without a rapid, focused response to its environment.

JPL has been successful in the past by responding to the nation's needs during the Cold War. That era has passed and a new one is evolving. The Laboratory today is concentrating its creative energies on satisfying customer needs, developing exciting, yet low-cost, missions of scientific discovery, modifying its internal processes, improving its business practices and contributing to the economic and social vitality of the nation. The Laboratory intends to transform itself so that it can do what no one has done before.

E. C. Stone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CELEBRATION AND CHANGE IN 1994

In 1994, JPL celebrated the 50th anniversary of a major change in its history — the June 1944 signing of a contract with the U.S. Army to begin development of a long-range missile for use during the Second World War.

The Army contract began the transformation of what until then had been the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT) into today's JPL. GALCIT had been a small research laboratory within the California Institute of Technology (Caltech), with a staff of less than 100 graduate students and technicians, an annual budget of a few hundred thousand dollars and a charter to conduct basic rocketry experiments. The JPL of today — an operating division of Caltech, performing research and development for the National Aeronautics and Space Administration (NASA) — has some 5,900 employees, an annual budget of approximately $1 billion and a wide-ranging charter for Solar System exploration, Earth observations, astrophysical research and technology development.

As it happened, this 50th anniversary coincided with a new round of changes taking place at JPL — changes affecting its organizational structure, the size and makeup of its work force, the way it designs and builds spacecraft, the way it operates missions and the way it conducts business.

Major transformations like this are always a response to some forcing event. In JPL's case, the forcing event has been a rapid and radical alteration to the environment that, since 1959 (the year the Laboratory was transferred from the Army to NASA), had been a very favorable one for the nation's civil space program. In the span of just the last few years, we have witnessed:

• The dissolution of the former Soviet Union. Space exploration is no longer the competitive international arena it was only a decade ago. Instead, cooperation is now the norm and the Laboratory is forging new relationships with European, Japanese and Russian space organizations.

• A new political environment. The November 1994 elections are widely regarded as a sea change in the U.S. political agenda. There has been speculation about reorganizing the nation's science and engineering resources, but it remains to be seen what directions the new Congressional leadership will take.

• Sharp cutbacks in Federal spending. Every Federal agency, including NASA, must confront the prospect of shrinking budgets into the early years of the next century and consider the impact of these reductions on programs and personnel. And, of course, whatever affects NASA affects JPL.

• The decline in the U.S. aerospace industry. As U.S. Department of Defense funding has tapered off, aerospace firms are looking for other business opportunities in which to apply their manufacturing and technological skills. JPL is exploring new partnerships with these companies.

Recognizing these changes, JPL has begun to reinvent itself to meet the challenges of the 21st century. The Laboratory has embraced the complementary concepts of Total Quality Management and "reengineering business processes" as it moves toward becoming a more efficient organization — meeting customers' requirements quickly, with scrupulous attention to costs and schedules, while maintaining traditionally high standards of scientific and engineering excellence

Toward that end, JPL is looking at its spectrum of skills to see how these can best be used in service to NASA and the nation. The Laboratory has significant capabilities in several areas: planetary exploration; telecommunications (the management and operation of the Deep Space Network, NASA's worldwide system for communicating with spacecraft); science support for NASA's Mission to Planet Earth and astrophysics (particularly in the detection and analysis of long-wavelength radiation); robotics; supercomputing; microelectronics and microdevices, and certain classes of sensors

RETURN TO MARS AND SATURN

Planetary exploration has been the hallmark of JPL's activities for more than 30 years. Since its Mariner 2 spacecraft cruised past Venus in 1962, JPL spacecraft have flown by or orbited the Sun and every planet in the Solar System, save Pluto. These missions have returned staggering quantities of data — from images of planetary surfaces and moons to measurements of temperatures, atmospheric pressures and electromagnetic environments. And yet, despite this bounty of information, scientific investigation of the Solar System has only begun.

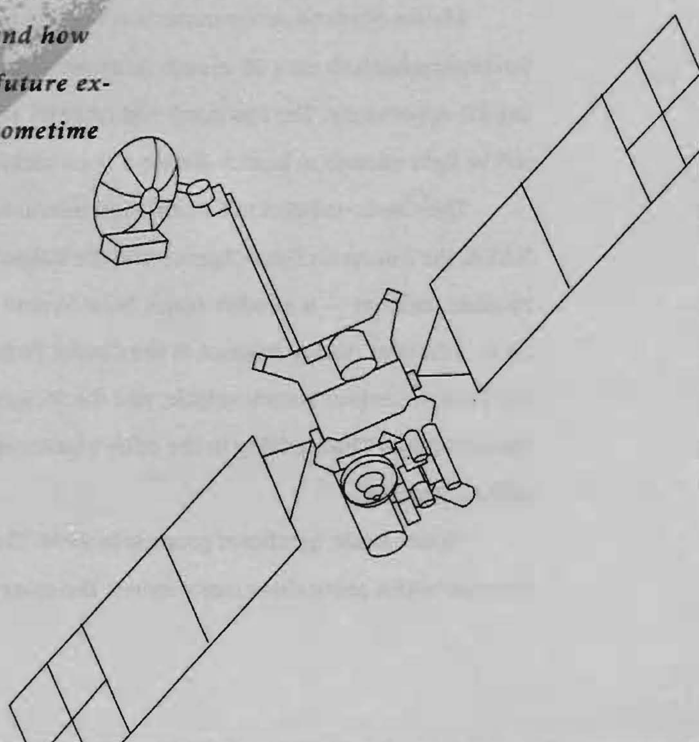
Mars — roughly half the size of Earth, yet marked with disproportionately large volcanoes, canyons and riverine features — was examined by six JPL spacecraft in the 1960s and 1970s. The planet is once again the focus of scientific attention; in 1994, JPL established a Mars Exploration Program Office to create a series of low-cost missions to this intriguing body between 1997 and 2005. These ventures will pick up where the Mariner and Viking missions left off and should expand understanding of the so-called Red Planet.

The first two new Mars spacecraft are Mars Pathfinder and Mars Global Surveyor, the first being built at JPL and the second at the Denver, Colorado,

*T*HE LURE OF MARS

The touchstone of the planned, decade-long exploration of Mars by NASA and JPL is the search for water — when, if ever, was it present on the Red Planet, over what regions and in what quantities? The search for water underlies the three primary areas of Martian exploration:

- *Evidence of past or present life. Although neither of the two Viking spacecraft found any indication of living organisms at their two landing sites in 1976, it remains to be seen if some form of life, however primitive, might have existed on Mars at one time. If water was present once, the Martian environment might have been warm, wet and dense just long enough to allow some primitive life-forms to begin evolving. The challenge for JPL engineers and scientists is to design experiments and equipment capable of recognizing subtle, perhaps even cryptic, hints of such processes.*
- *Climate and weather. The Mars Pathfinder and Mars Global Surveyor spacecraft will look for subsurface reservoirs of water and closely examine the polar caps of frozen carbon dioxide (dry ice) and water ice. The form, locations and extent of these reservoirs should tell us about Mars' climatic history — and could provide insights into Earth's history of intermittent ice ages.*
- *Resources. What is the interior of the Red Planet like? Is it presently active, and if so, how is that activity manifested? What near-surface materials and volatile compounds are present and how are they distributed? Answers to these questions will shape future explorations of Mars, including, perhaps, human expeditions sometime in the 21st century.*



plant of the Laboratory's partner, Martin-Marietta Astronautics. Both missions are to be launched toward Mars in late 1996, within a month of each other.

Mars Pathfinder, arriving at the planet in the summer of 1997, is to be a proof-test of an innovative engineering concept for placing robotic spacecraft safely on a planetary surface with as small a retropropulsion system as possible. This concept envisions a combination of an aeroshell, parachutes, small solid-fuel rockets and air bags to slow and lower a spacecraft in a planetary atmosphere, and, finally, to land it on the surface. Once there, the landing platform — itself a functioning spacecraft — will deploy a microrover onto the surface to conduct science experiments. NASA has capped Mars Pathfinder costs at $171 million over the course of three years and JPL is carrying out the project within budget.

Mars Global Surveyor, entering near-polar orbit around the planet in the fall of 1997 (using the aerobraking technique experimentally demonstrated by JPL's Magellan mission to Venus), will spend two years mapping the planet's surface topography, geochemical composition and weather patterns. The lessons learned from the earlier Mars Observer mission are being applied to the design and manufacture of the new spacecraft: Changes have been made to the propulsion system to preclude premature mixing of its hyperbolic propellants, identified as the most likely cause of the Mars Observer failure. Mars Global Surveyor will be a less costly spacecraft to develop than the earlier mission ($154 million versus $510 million) because it will incorporate surplus Mars Observer hardware and software, will be lighter (650 versus 1,100 kilograms) and will be launched by a less expensive rocket (a $50 million Delta versus a $350 million Titan 3/Transfer Orbital Stage).

Martin-Marietta Astronautics was selected to build the Mars Global Surveyor spacecraft on a 26-month timetable to meet a late-1996 planetary launch opportunity. The spacecraft will carry six science instruments, but will still be light enough to launch aboard a Delta rocket.

The Cassini mission to Saturn — an international venture involving NASA, the European Space Agency and the Italian space agency (Agenzia Spaziale Italiana) — is another major Solar System exploration effort in development. Last year, NASA assigned to the Cassini Project Office responsibility for the Titan 4/Centaur launch vehicle, and the Huygens probe to be landed on Saturn's moon Titan, adding to the office's basic responsibility for the Cassini orbiter spacecraft.

Cassini made significant progress in 1994. The project was recertified to reassure NASA about three major issues: The spacecraft can still be launched to

Saturn in 1997 by the Titan 4/Centaur rocket; it remains a world-class mission, despite a reduction in development funds, and its operational and analytical costs will not exceed NASA's funding cap.

Innovations in Mission Design

In the design and fabrication of Mars exploration spacecraft and other projects, JPL is applying Total Quality Management concepts to mission assurance, a new approach perhaps best expressed by the adage, "Don't inspect quality into the product after manufacture; design it into the process." Toward this end, JPL has recently created two key facilities: the Project Design Center and the Flight System Testbed.

The Project Design Center, a network of nine computers linked to a common database and housed in a 220-square-meter office, provides an environment where engineers, scientists and support personnel can work together — and concurrently — on the major elements of a new mission, including science goals, hardware, software and operations. Projects such as Pluto Express, Mars Pathfinder, Mars Global Surveyor, the Space Infrared Telescope Facility (SIRTF) and others are already using the Center's capabilities.

A team from the Pluto Express predevelopment office, for example, uses the Center to engage in imaginative "brainstorming" sessions about the mission to explore the ninth and only unvisited planet in the Solar System. In a given session, the team tackles any number of issues: What if the size of the Pluto Express antenna were increased? How much more data could be transmitted and at what rate? Could transmitter power be reduced? How much additional mass would a bigger antenna add to the structure? Would that greater mass affect the launch vehicle's performance? Would the cost of a larger antenna adversely affect the project's funding cap? Could such an antenna be developed in time to meet the schedule? The Center allows engineers to obtain answers to questions like these in real time — and share the information promptly with all other team members.

A tool complementary to the Project Design Center and equally valuable is the Flight System Testbed, a complex of three test stations and separate computer network in a 170-square-meter room. The Testbed allows engineers and scientists to work out the problems of new designs (or new technologies) very early in a project's life cycle. For example, a project office might want to determine how well an advanced camera system would work in an evolving spacecraft design. By mounting a prototype camera on a test station and connecting it to computers that simulate the spacecraft and ground systems, engineers can create a "virtual" spacecraft, put it through its paces and make the necessary determination.

NASA intends to revolutionize space exploration in the 21st century by flying more missions — addressing a broader spectrum of scientific questions — more frequently and yet at lower cost. JPL's Project Design Center and Flight System Testbed both represent important means to helping achieve this goal. The Laboratory and its industrial partners are already investigating a new generation of small, versatile spacecraft and instruments that will take less time and money to build and operate than anything previously flown in space. The Laboratory's New Millennium program, a good example of this forward-looking effort, will develop and flight-qualify a set of advanced technologies that will radically change the character of space exploration.

The New Millennium program focuses on areas such as autonomous mission operations, miniaturized and microsized machinery and sensors, microelectronics, telecommunications and advanced materials and structures; JPL approaches the development of each of these technologies with design-to-cost as the paramount concern. Laboratory personnel pursue vigorously the best-possible performance, but not at the risk of exceeding budgetary limits or missing scheduled milestones.

The New Millennium program holds out intriguing possibilities: Very compact and integrated planetary orbiters or landers, weighing just a few tens of kilograms, would effectively be on their own once launched. These spacecraft would self-navigate to their targets, steer themselves into orbit (or down onto a surface) and report back to Earth only when downloading data or facing a problem that their onboard systems could not handle. Such operational autonomy would greatly reduce the need for ground-based support. Many missions could operate simultaneously in different corners of the Solar System, without swamping the Deep Space Network with up- and downlink transmissions of routine information.

Looking beyond these small-spacecraft concepts, JPL engineers can envision an even more advanced generation of exploratory spacecraft and probes called "spacecraft-on-a-chip" — a complete set of systems reduced to integrated circuits and microdevices mounted on a single substrate. Clusters of these tiny, silver dollar–sized probes could be dispersed into, for instance, the Jovian magnetosphere or the Venusian atmosphere, with their measurements relayed back to Earth via an orbiting mother spacecraft.

Solar System exploration missions in development at JPL include Mars Pathfinder and the Cassini mission to Saturn. Clockwise from upper left: A full-scale model of the Mars Pathfinder Launch Vehicle Adapter Ring. The Mars Pathfinder Power Subsystem breadboard, which is used to assess design options quickly. Full-scale models of the Cassini Upper Equipment Module, to carry a number of science instruments, and the Cassini Launch Vehicle Adapter. Integration of the Cassini Attitude and Articulation Control Subsystem breadboards. Full-scale models of the Cassini instruments located on the remote-sensing pallet.


REMOVE BEFORE FLIGHT
REMOVE BEFORE FLIGHT
REMOVE BEFORE FLIGHT
REMOVE BEFORE FLIGHT

It might be possible someday to combine the spacecraft-on-a-chip concept with another new technology — inflatable/deployable structures — to create large, lightweight booms, antennas, reflectors or even complete spacecraft. JPL and an industrial partner, L'Garde Inc., of Tustin, California, are at work on a 14-meter-diameter antenna that is made of aluminized Mylar film and Kevlar and is parabolic in form when inflated. Folded into a small volume, the antenna will be proof-tested during a space shuttle mission in 1996.

The antenna could be the forerunner of even more advanced inflatable structures, equipped with systems and sensors "on-a-chip" and packed into a volume no bigger than a bass drum. Once launched by small-to-medium rockets into space and inflated by a gas pressure as little as 133×10^{-6} pascal (approximately 1/10,000th of the air pressure at sea level on Earth), these fully deployed structures could have the dimensions of a Hubble Space Telescope or Galileo spacecraft, but only a fraction of their mass. And if a particular mission called for a rigid structure, the inflatable material could be chemically coated so as to "set" when exposed to solar ultraviolet or infrared (heat) radiation.

In another effort to revolutionize space exploration, NASA last year challenged the space science community to submit creative ideas for a new class of low-cost planetary and astrophysics missions called Discovery. Each Discovery mission will cost less than $150 million to develop and less than $240 million total, including launch and operations. The response to the NASA challenge from universities, industry, JPL and other NASA field centers was impressive.

JPL submitted several ideas in conjunction with various university and industrial partners. These include a spacecraft that would fly through the coma, or tail, of an active comet, taking images and returning samples of coma dust to Earth for more detailed analysis; a spacecraft that would collect samples of solar particles streaming outward from the Sun and return them to Earth for further analysis, and a spacecraft that would transport 16 small probes to Venus, scattering them throughout the planet's atmosphere to study its unusual circulatory patterns.

STUDIES OF THE DISTANT UNIVERSE

The Laboratory's inquiries are not limited, however, to the other bodies of the Solar System, but extend beyond to the distant Universe. There is a rich lode of scientific data about galaxies and galactic processes to be mined in the longer wavelengths — infrared and submillimeter — and JPL has two missions under development to extract that information: the Wide-Field Infrared Explorer (WIRE) and the Space Infrared Telescope Facility (SIRTF).

WIRE is a cryogenically cooled telescope with a 30-centimeter aperture that will look for both "starburst" galaxies, systems already formed where large numbers of stars are forming in localized regions, and protogalaxies, starry systems just in their infancy. This small, simple spacecraft will operate for about four months and explore two wavelengths (12 and 25 micrometers) with a sensitivity 500 times greater than that of the Infrared Astronomical Satellite. JPL's partner in the $50 million WIRE project is Utah State University.

SIRTF, one of NASA's four great observatories, will broaden and deepen the investigations of both the WIRE and Infrared Astronomical Satellite missions. SIRTF will explore a wider band of infrared frequencies with a spectrometer (3.5- to 40-micrometer wavelengths) and an imaging camera (10- to 180-micrometer wavelengths).

Responding to NASA's requirements for a smaller, less costly space observatory, JPL has reduced the mass of SIRTF from 5,700 to 750 kilograms and the cost from $2 billion to $400 million over the last two years. Perhaps the most significant change to the mission has been the idea of placing SIRTF in solar orbit, trailing — instead of orbiting — Earth. Earth orbit is not an optimal arena for an observatory like SIRTF because observation time is limited to the night side of the planet. Also, reflected heat and light from Earth create thermal problems and ground operations are complex. These and other problems would be minimized in solar orbit as the spacecraft drifts to about 50 million kilometers behind Earth during the course of its 2.5-year-long lifetime.

Another JPL instrument, the second Wide Field/Planetary Camera, began operating aboard the Hubble Space Telescope in 1994, and its performance was widely hailed. After the telescope's primary mirror was discovered in 1989 to have a spherical aberration that made it impossible to focus collected light sharply enough, JPL was asked to redesign the second camera (already under development) to compensate for the flaw and, moreover, to do so in time to meet a scheduled December 1993 servicing mission. The redesign included an adaptive optics system with a new secondary mirror (about the size of a dime) shaped so as to counter the aberration — and a series of still smaller adjustable mirrors that could be commanded to tilt or tip to tighten the focus even more.

Successfully substituted for the first Wide Field/Planetary Camera during the 1993 servicing mission, the second JPL camera underwent an extensive checkout at the start of 1994 and then began taking a series of breathtakingly clear images, capturing objects both within and far beyond the Solar System:

• Newborn stars in the Orion nebula, surrounded by planet-forming disks no more than a few hundred thousand years old.

• Complex patterns of ejected material from the exploding star Eta Carinae.

• Forty Cepheid stars in the Virgo Galaxy M100 whose variable brightness has long been used as a cosmic yardstick and should now enable astronomers to calculate the precise rate of the Universe's expansion for the first time.

• Red dwarf stars, hypothesized to be as numerous throughout the Universe as sparrows on Earth and so accounting for upward of 90 percent of the "missing mass" of the Universe, but revealed by the JPL camera to be rare.

• A spectacular storm raging high in Saturn's upper atmosphere.

JPL's second Wide Field/Planetary Camera restores the Hubble's capabilities to original specifications, enabling the telescope to see farther into the Universe, with greater sensitivity and acuity, than any other telescope.

Through these missions, and possible participation in an international infrared space telescope being planned for the next century, JPL scientists expect to answer some of the more puzzling questions about the early stages of the Universe's evolution.

SOLAR SYSTEM EXPLORATIONS

For JPL's long-term, deep space missions, 1994 was an eventful year. Galileo, which has been sailing toward Jupiter since 1989, was able to observe the fiery destruction of a comet that collided with the Solar System's largest planet. Ulysses, meanwhile, passed by the Sun's south pole and is soaring toward the solar north pole. And Magellan last year concluded an extraordinary 5.5-year-long mission at Venus, plunging into the Venusian atmosphere in a "wind-milling" experiment that extracted useful science data up to the last second of the spacecraft's operation.

Galileo, on final approach to Jupiter, found itself in the right place at the right time last summer as the fragments of comet Shoemaker–Levy 9 plowed into the far side of Jupiter. It was truly cosmic theater — the first time humanity has had an opportunity to witness a collision of celestial objects.

But the collisions took place not on Jupiter's center stage, where they would have been immediately visible to ground-based telescopes and Earth-orbiting spacecraft, but off-stage, just around the limb as seen from Earth. Galileo happened to be in a position where its sensors could see the impacts of fragments G, H, K, L, N, Q1, R and W as they occurred and so provided valuable

COMMUNICATIONS/ SCIENCE

Spacecraft communications and scientific experimentation are two important functions of the JPL-managed Deep Space Network. Top: The 34-meter research and development antenna at the Network's Goldstone, California, site is used as a testbed for new technology. Center: The Data Systems Operations Team monitors spacecraft telemetry. Lower left: Laser excitation improves the performance of the linear ion-trap atomic clock for use in Network radio-science experiments. Lower right: This ultrahigh-frequency radio modem will allow the Mars Pathfinder lander and its deployed microrover to communicate on the Martian surface.

information on the sizes, temperatures and other properties of the fireballs during the first few minutes of the collisions.

In particular, the impact of fragment G was recorded by three of Galileo's instruments — the Near-Earth Mapping Spectrometer, the Photopolarimeter Radiometer and the Ultraviolet Sensor. This was the first time in history that a comet impact had been directly characterized. Estimated to be up to 2 kilometers in diameter, fragment G created a fireball with a temperature of some 7,700 degrees Celsius — hotter than the surface of the Sun — as it smashed into the Jovian atmosphere. Five minutes later, the fireball had expanded to hundreds of kilometers across and had cooled to 130 degrees Celsius.

Because of widespread interest in the comet collision, JPL created a "Shoemaker–Levy Homepage" on the World Wide Web of the Internet. The Homepage became an electronic repository for hundreds of impact images and scientific information gathered worldwide by instruments in space and on the ground. By the end of 1994, the Homepage had been accessed some 3.4 million times, reflecting the intense public interest in the event.

Earlier in 1994, Galileo played back the tape-recorded data of its August 1993 encounter with the asteroid Ida. Ida turns out to be an irregular, S-type body (the most common) 55 kilometers long and 15 to 20 kilometers at its widest. Scientists were surprised, however, when their review of Galileo images revealed that the asteroid has a moon of its own, a tiny object (later named Dactyl) 1.4 kilometers in diameter and trailing 100 kilometers or so behind the larger body.

The Galileo team spent much of 1994 preparing for the Jupiter arrival of the spacecraft, which consists of an Orbiter and a Probe, in December 1995. Critical engineering sequences were written for the release of the NASA Ames Research Center–developed Probe; for the receipt of data from the Probe during its high-speed descent into the Jovian atmosphere, and for the Orbiter's insertion into orbit around Jupiter at almost the same time as the Probe's descent.

The Galileo team also continued work on ways to speed the transmission of data from the Orbiter's low-gain antenna, the primary link between the spacecraft and Earth since the umbrella-like high-gain antenna failed to deploy fully. New data-editing and -compression techniques will allow the same information to be returned with 10 or 20 times fewer bits; this should dramatically increase the data return for Galileo's two-year, 10-orbit tour of the Jovian system. Close-up images of the planet's four Galilean moons, which will be gathered by the Orbiter, are expected to be 100 to 350 times better than those taken by the two Voyagers in 1979.

Ulysses, launched in 1990, is the first spacecraft to orbit the Sun at a high-enough angle to observe the solar poles. Last September, its trajectory having been warped out of the ecliptic plane by a close flyby of Jupiter in 1992, the spacecraft returned to the inner regions of the Solar System and dove to 80 degrees south latitude. There, for the first time, scientific instruments glimpsed the Sun's south polar region.

Scientists in the United States and Europe (the project is an international effort between NASA and the European Space Agency) had expected that the Sun's magnetic field would be similar to Earth's — that is, tightly bunched at the poles and spread out, like a whisk, as it arches high above mid-latitudes and the equator That is not quite what Ulysses found, however.

The strength of the solar polar field turned out, surprisingly, to be roughly the same as that of the solar equator field, suggesting that the Sun's magnetic field is not as bunched at the poles as Earth's is The explanation offered by one of the Ulysses science teams is that the powerful solar wind — a high-velocity ion stream — spreads out the Sun's magnetic field at the poles and, as it flows outward, pushes the magnetic flux lines in the direction of the equatorial plane, dispersing them over the large distances reached by the wind.

Scientists have long known that the solar wind blows unevenly, alternating between high and low speeds. The slow wind has been theorized to originate in equatorial regions and the fast wind in coronal holes at the poles. As Ulysses moved toward higher latitudes, scientists expected that the solar wind there would pick up speed and flow in a more orderly way. Indeed, that is what the spacecraft observed: a steady stream of electrified gases blowing at 750 kilometers a second, or 2.7 million kilometers per hour.

Ulysses also made a discovery about cosmic rays. Prior to the spacecraft's solar passage, it was thought that these very energetic particles shooting into the Solar System from other regions of the Milky Way Galaxy would be twice or more as abundant at the Sun's poles than at the equator because of the funneling effect of bunched magnetic fields. In fact, the spacecraft detected only slightly greater counts of cosmic rays coming into the south pole than it had measured in equatorial regions. This unexpected finding was due to large, irregular changes in the direction of the magnetic field, caused by waves that originate in the Sun and are continuously present over the polar cap. These irregularities appear to block cosmic rays around the poles and deflect them back out to space. Ulysses is to fly over the solar north pole in 1995 and scientists are eagerly awaiting the results from that pass

Many questions still remain about the Sun and its dynamics. As a result, NASA is considering a follow-up, joint U.S.–Russian project called FIRE that would involve two spacecraft sweeping close to the Sun Solar Probe, the U.S. spacecraft, would come within 4 solar radii of the Sun, well inside the solar corona The Russian spacecraft, called Tsiolkovsky in honor of that nation's great scientist, would approach to within 10 solar radii of the Sun.

This mission, undoubtedly one of the most challenging ever undertaken by JPL, envisions a 160-kilogram spacecraft bearing a set of four scientific instruments — a plasma spectrometer, plasma wave detector, magnetometer and disk imager sensitive to visible and ultraviolet wavelengths. Perhaps its most innovative element is a high-gain antenna that would also serve as a heat shield; the antenna, parabolic as well as elliptical in shape, would be 1 to 1.5 meters at its widest, 2.5 meters long and made of a carbon–carbon material that would withstand the intense thermal and radiation environment close to the Sun.

OBSERVING EARTH FROM SPACE

In addition to conducting extensive interplanetary research during 1994, JPL made discoveries closer to home, where its Earth-orbiting satellites and instruments addressed a broad set of questions fundamental to life on this planet.

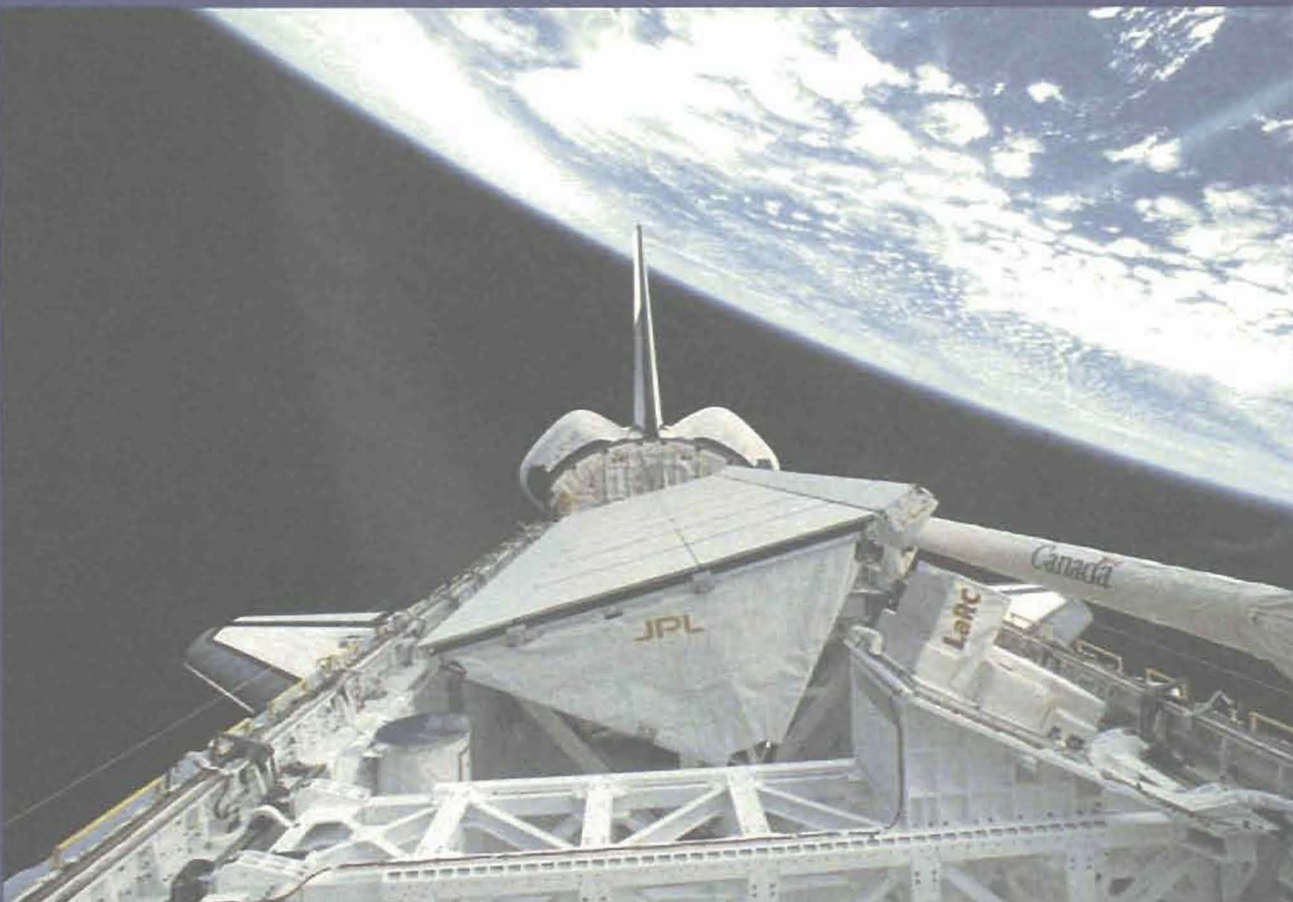
TOPEX/Poseidon (for Topographic Ocean Experiment and the Greek god of the sea) is a joint NASA–JPL venture with the French space agency, Centre National d'Études Spatiales. Launched in 1992, the satellite has performed superbly in measuring the dynamics of the world's oceans with a radar altimeter and a radiometer. The altimeter measures the global ocean topography, relative to Earth's geoid, with an accuracy of 2 to 3 centimeters — with the radiometer providing corrections for errors in the data caused by atmospheric water vapor.

Last year, the project made two important discoveries. The first was that the effects of an El Niño phenomenon in the Pacific Ocean are longer-lasting and wider-spread than previously thought. El Niño is a great surge of warm ocean water that sweeps eastward across the equator every three to four years when westerly winds weaken and can no longer hold the ocean mass against the Asian continent.

The event is disastrous for landforms and life alike: Torrential rains and heavy snows, stemming from storm tracks driven far south of their usual paths, fall on the west coasts of North and South America and the surge itself overrides cooler Eastern Pacific waters, smothering the upwelling process that brings nutrients to the surface. Without those nutrients, fish and bird populations decline rapidly

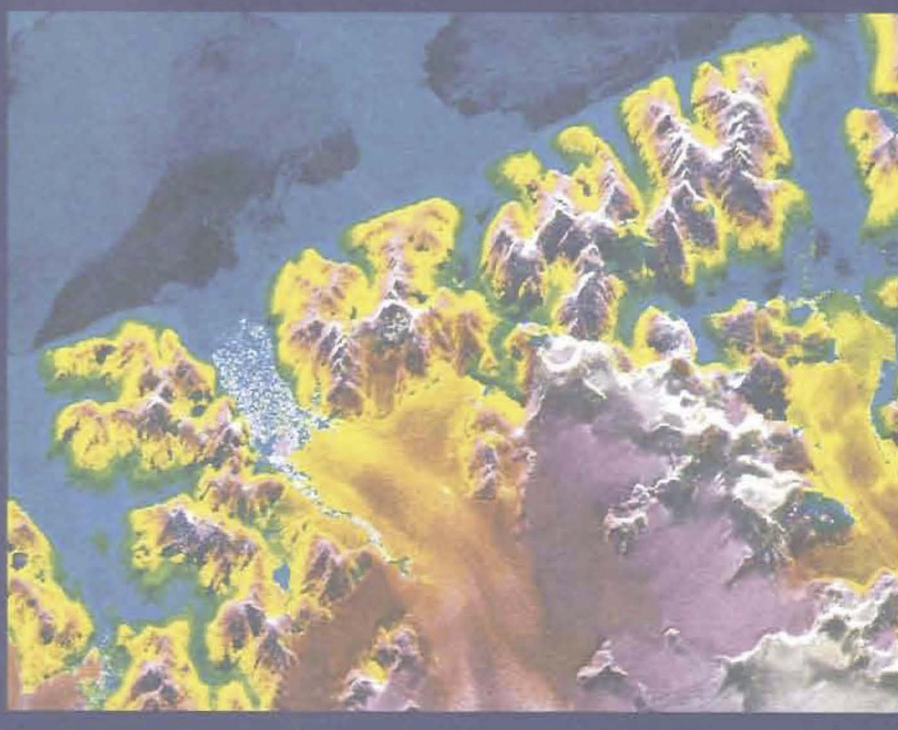
Both Earth and the Universe swam into breathtaking view last year, thanks in part to contributions by JPL: The Spaceborne Imaging Radar–C/X-band Synthetic Aperture Radar (SIR-C/X-SAR), a joint U.S.–German–Italian mission, flew twice on the space shuttle, observing key sites around the world. Aboard the Earth-orbiting NASA Hubble Space Telescope, the second Wide Field/Planetary Camera revealed objects within and far beyond the Solar System, making major discoveries.

Within Herbig-Haro object HH30, a star and its planetary system are forming inside a disk of dense gas and dust. In this camera image, the HH30 star is hidden between the two orange–yellow nebulas.



From the payload bay of the space shuttle Endeavour, SIR-C/X-SAR gathered data on Earth's environment. In the background is an area of the Pacific Ocean northeast of Hawaii.

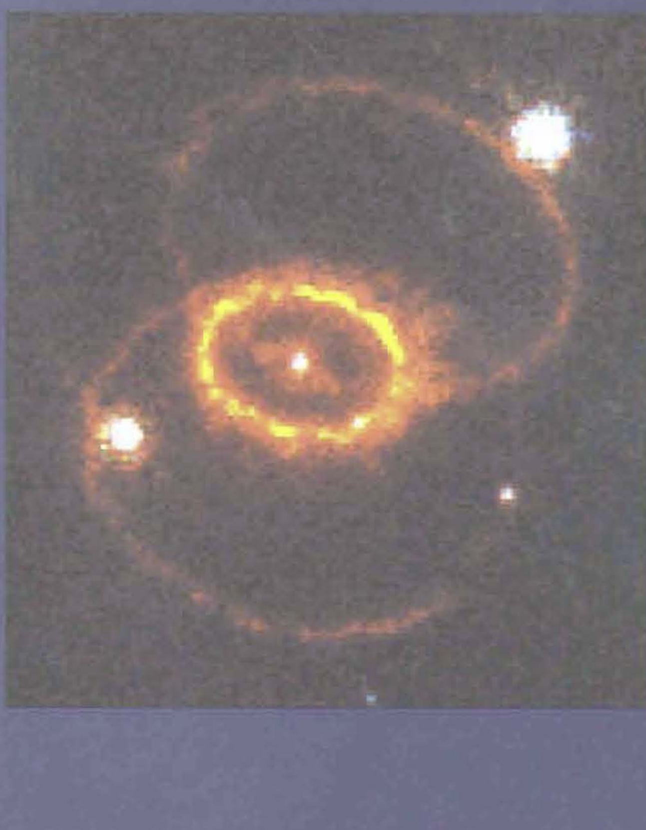
As the fragments of comet Shoemaker–Levy 9 collided with Jupiter in July 1994, the camera recorded in this photo-mosaic an explosive plume (lower left) and impact debris (dark features).



Chile's huge Patagonia ice fields are highlighted by the space radar. Terrain height ranges from zero to 2,000 meters, with low elevations shown in blue and high elevations in pink.

On the island of New Britain, Papua New Guinea, the Rabaul volcano erupted in 1994. In this radar view, ash deposits from the eruption appear as red areas around the large bay and pumice fragments as a color change at the top of the bay.

The Mississippi River Delta, where the river flows into the Gulf of Mexico, is shown in this radar image. The main shipping channel, seen as a thick vertical line, runs northwest to southeast.



Supernova SN1987A exploded 170,000 light-years from Earth, leaving a triple-ring structure as seen in this false-color image from the camera. The bright central object contains the remains of the supernova star.

TOPEX/Poseidon has found that an El Niño does not dissipate after hitting the Americas, as had been thought, but instead ricochets back toward Japan and Australia. There, its effects — although diminished — are felt for several years. Several such surges can follow each other around the Pacific at three- to four-year intervals, extending their disruptive effects for as long as a decade

TOPEX/Poseidon also found that the global mean sea level has risen 2 millimeters every year since 1992, an increase that might be caused by melting ice from polar regions or by the expansion of warm oceanic waters. Given the scant data collected so far, this trend could be either the first sign of long-term global warming — a very serious consequence of "greenhouse" gases pumped into the atmosphere by human activities — or simply a short-term climatic fluctuation. Measurements collected by the oceanographic satellite in the near future should resolve this issue Beyond that, TOPEX/Poseidon findings are expected to lead to a deeper understanding of oceanic dynamics, with benefits in improved weather forecasting, commercial shipping and fisheries, pollution abatement and oil exploration.

Another key JPL tool for Earth observations is the Microwave Limb Sounder Flying aboard NASA's Upper Atmosphere Research Satellite 600 kilometers above Earth since 1991, this instrument scans the stratosphere for chemicals involved in the depletion of the planet's protective ozone layer — including the predominant form of chemically reactive chlorine. Stratospheric chlorine comes mainly from chlorofluorocarbons (CFCs) — widely used refrigerant and industrial gases — and destroys ozone.

The Microwave Limb Sounder, which earlier had confirmed chlorine chemistry as the cause of the ozone hole over Antarctica and provided the first maps of elevated levels of reactive chlorine over both the Antarctic and Arctic regions, last year definitively showed a chlorine-linked loss of ozone over the Arctic. Arctic loss is not as severe as that which typically occurs over the Antarctic, a difference attributable to the fact that stratospheric temperatures there do not fall as low, or remain low as long, as they do over the Antarctic. Low temperatures lead to the formation of polar stratospheric clouds that convert chlorine into its destructive forms.

The Laboratory last year also took the measure of Earth's surface with a radar mapper, the Spaceborne Imaging Radar–C/X-band Synthetic Aperture Radar (SIR-C/X-SAR). SIR-C was developed by JPL; X-SAR was developed by the German space agency, Deutsche Agentur fur Raumfahrtangelegenheiten, and the Italian space agency, Agenzia Spaziale Italiana. The large, integrated instrument, filling the cargo bay of the space shuttle, flew two Earth-orbital

The Deep Space Network

Of all JPL's capabilities and responsibilities, the Deep Space Network extends deeply, like a tap root, into the Laboratory's history. The Network was founded in January 1958 when JPL — still under contract to the U.S. Army — deployed portable radio tracking stations in Nigeria, Singapore and California to receive telemetry signals from Explorer 1, the first Earth-orbiting U.S. satellite. After becoming part of NASA in 1959, the Laboratory established permanent stations for deep space telecommunications at three sites approximately 120 degrees apart around the globe: Goldstone, California; Madrid, Spain, and Canberra, Australia.

In addition to providing communications and tracking for interplanetary and low-Earth-orbiting spacecraft, the Deep Space Network carries out scientific experiments. In 1994, JPL scientists used the 70-meter-diameter Solar System radar at Goldstone to image the asteroid 1620 Geographos when it came within 7.2 million kilometers of Earth, its closest approach for at least the next 200 years. Computerized reconstruction of the radar echoes revealed Geographos to be a fascinating and unusual object, some 5.1 kilometers long and 1.8 kilometers wide. This asteroid has the largest length-to-width ratio of any object yet observed in the Solar System; it has yet to be determined if it is one, coherent object or two or more fragments moving in formation.

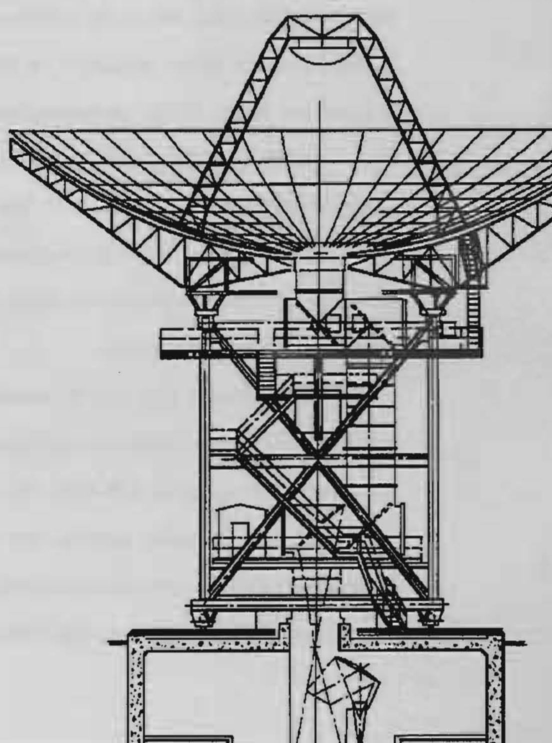
In other observations, JPL scientists studied another asteroid, Castalia, using the National Science Foundation's Arecibo Radio Observatory in Puerto Rico. Castalia appears to be a two-lobed body less than 2 kilometers across. The detailed, three-dimensional radar images that were obtained — the first such of an asteroid — confirmed that asteroids are the most irregularly shaped objects in the Solar System, probably because of countless collisions with other fragments remaining from the Solar System's earliest times.

The Deep Space Network's effectiveness depends to a large extent on the ability of JPL engineers and scientists to develop technology that will support future missions at the lowest cost and yet with the highest reliability and flexibility. In 1994, for example, Network engineers found a way to link, through conventional telephone lines, spacecraft operating in low Earth orbit and the associated principal investigators anywhere in the world. The link is made possible by a small, automated, ground-based antenna called LEO-D (Low Earth Orbit Demonstration), which can be accessed through telephone lines. Investigators can direct the antenna terminal to acquire data from an Earth-orbiting satellite and return that information to their own computers.

Engineers in 1994 also developed an ionic clock, called a linear ion-trap standard, which is more precise than any atomic clock now in operation. The new clock will help scientists conduct a broad range of radio-science experiments over great distances by detecting extremely small perturbations in radio signals sent from Earth to a spacecraft and back again. Gravitational waves rippling through the Solar System would perturb an Earth–spacecraft system by a very small amount, distorting the round-trip time of a radio signal ever so slightly. The ion-trap clock, however, is capable of measuring a picosecond (1×10^{-12} second) variation in a 1,000-second observation period — about the magnitude of variation that would be expected in signals between Earth and the Cassini spacecraft at Saturn. Such variations, if observed repeatedly, would be construed as direct evidence of the existence of gravitational waves.

The Deep Space Network is constantly changing to meet the demands of new space missions. Over the years, its three sites have acquired a variety of antennas: 70-meter-diameter units (one at each site); 34-meter-diameter units (Goldstone has a total of eight — five in service, one on standby and two under construction — while Madrid and Canberra each have two in service, with a third under construction at each site), and smaller-diameter units at each site. Major strides were taken in 1994 toward completing construction of the four new 34-meter beam-waveguide antennas at the three sites.

With their multifrequency systems, the new 34-meter antennas — operating alone or in arrays with other antennas — will be able to support JPL's far-flung spacecraft. The antennas will capture S-band data from the Galileo spacecraft after it enters orbit around Jupiter, K-band radio-science data from the Cassini spacecraft when it arrives at Saturn soon after the turn of the century, Ka-band telemetry from New Millennium spacecraft when they begin flights in another few years and X-band science data from the two Voyager spacecraft as they approach the heliopause, the boundary between the Solar System and interstellar space, at a distance of 200 astronomical units.



missions, each lasting 11 days, in the spring and fall and took some 20,000 radar images of volcanoes, flood-devastated regions of the U.S. and Brazil, a tropical cyclone and specific forest sites around the world.

Both flights could not have occurred at more opportune times: The first took images of the still-active Mount Pinatubo, a volcano in the Philippines; the second caught Kliuchevskoi, a volcano on the Kamchatka Peninsula, Russia, just hours after it began erupting. A comparison of the April and October images of Pinatubo disclosed mud flows moving down the volcano's sides and demonstrated just one of the useful aspects of such radar data.

SIR-C/X-SAR also peered down on the upper Mississippi River drainage basin, so badly flooded in 1993, and identified wide areas now overlain with sand deposits and hence not presently suitable for planting. Federal and state agricultural agencies will be using this information as they work on long-term recovery efforts.

The instrument also mapped the area extent and volume of the snow pack in the Eastern High Sierras of California and in the Austrian Alps to determine just how much water could begin flowing when spring thaws come. The information gathered in 1994 was intended to prove the underlying concept, but flood control agencies should find such data very important in the future

Even human history can be read in the SIR-C/X-SAR data, because the microwave pulses emitted by the radar can penetrate dry sand or vegetation to varying depths before being reflected back up to the instrument's antenna. The SIR-C/X-SAR team pursued a 1992 Landsat satellite discovery of what might be the ancient city of Ubar in southern Oman, on the Arabian Peninsula. The team uncovered a network of roads and buried riverbeds that converges on the city, suggesting that this site could have been Ubar, a major trade center that flourished from about 2800 B.C. to 300 A D Preliminary excavations are being carried out at the site by archeologists using the SIR-C/X-SAR images

Similarly, the radar revealed the ruins of Niya, an ancient settlement under the sands on the legendary Silk Road in the Taklimakan Desert in western China. Scientists are also studying measurements collected around the pyramids in Egypt and the Angkor-Wat temple complex in Cambodia for hints of long-buried secondary structures.

SIR-C/X-SAR data can be combined with those from TOPEX/Poseidon and the Microwave Limb Sounder in ways that yield insights into terrestrial processes. For example, SIR-C/X-SAR can detect the movement of ocean water, while the oceanographic satellite can "see" the higher elevation of warm water. When the two data sets are correlated, currents like the Gulf Stream in the Atlantic and the Kuroshio in the Pacific take on a third, more realistic dimension.

Indeed, the space radar, with its three frequencies — X-band (3 centimeters), C-band (6 centimeters) and L-band (23 centimeters) — has suggested so many valuable applications that JPL is proposing a free-flying, Earth-orbital version that would monitor the planet continuously, just as TOPEX/Poseidon and the Microwave Limb Sounder do.

Technology and Applications Programs

The Technology and Applications Programs (TAP) Directorate carries out a broad range of work for NASA and other sponsors. For NASA, the directorate is developing advanced technologies that will be needed for future space exploration — such as microsized devices, supercomputer technologies, robotics and telerobotics, optics, rovers, advanced materials and structures, information systems, autonomous systems and power and propulsion sources. For non-NASA sponsors, it is applying JPL's special capabilities to technical and scientific problems of national significance.

In 1994, TAP was asked to extend the Corps Battle Simulation system — a computerized, interactive training program for U.S. Army brigade and battalion commanders — to other simulation systems representing higher and lower command levels. This addition significantly enhances the realism and fidelity of the various ground combat situations Army personnel might someday have to confront.

One of the directorate's major achievements in 1994 was the demonstration of an advanced camera system based on active-pixel sensors. These sensors, under development at JPL since 1992, are more like computer chips than charge-coupled devices (CCDs) — the dominant imaging technology of recent years — in that several functions (such as photon capture, signal amplification, timing and analog-to-digital conversion) can be sequentially deposited on a standard semiconductor substrate. Most of this work was conducted at JPL's Center for Space Microelectronics Technology, a facility sponsored jointly by NASA, the Departments of Energy and Commerce, the Advanced Research Projects Agency, the Ballistic Missile Defense Organization and industry.

JPL's demonstration camera is a 256- by 256-pixel array with integral timing and control circuits and needs only a power source and a lens to function as an imaging system. Although its resolution is presently not as high as a CCD unit's, the active-pixel camera needs less than a hundredth of the power required by a CCD camera and might someday find application in a broad range of science programs, as well as in consumer products ranging from video telephones and safety devices to toys.

Equally promising is another new camera system called Quantum-Well Infrared Photodetector. This unit is designed to capture very faint thermal radiation and could become an important element in the Mission to Planet Earth program by mapping pollutant gases, geologic structures and surface temperatures. It could also be used to capture infrared radiation from distant objects in the Universe.

TAP is also actively involved in transferring Federally sponsored technology to industry and other Government agencies. The Southern California firm of Allen Osborne Associates, for example, last year introduced a lightweight (4.3-kilogram) receiver that picks up the communications signals from the Global Positioning System, a Department of Defense network of 24 satellites orbiting 20,000 kilometers above Earth. The receiver, based on a JPL design from the late 1980s and called "TurboRogue," can track as many as eight Global Positioning System satellites simultaneously and thereby determine the relative positions of two or more locations on Earth with millimeter accuracy.

Such precision is of great interest to scientists monitoring the very slight movements of Earth's crustal plates for earthquake and volcano research. Indeed, JPL and U.S. Geological Survey scientists in 1994 used TurboRogue receivers to study the ground shifts caused by the Northridge, California, earthquake of January 17, 1994. Analysis of the temblor data revealed that Oat Mountain, a peak of the Santa Susana Range that borders the north end of the San Fernando Valley, was lifted 38 centimeters, and moved 16 centimeters north and 14 centimeters west of its prior position, as a result of the tremor. The receivers, in effect, captured mountain building in progress.

New Ways of Doing Business

The process of change at JPL is not limited to projects and systems development; the Laboratory is also changing its work force, its business practices and its organizational structure in response to the new environment.

JPL's annual budget ($1.05 billion in 1994, down from $1.1 billion in 1993) is sensitive to NASA's budgetary fortunes — and NASA faces an austere future. Because this projected austerity could affect program areas of major interest to the Laboratory, JPL believes it only prudent to plan accordingly. All Laboratory salaries were thus frozen for Fiscal Year 1995, an action also taken

Advanced technology created by JPL meets the needs of space applications and addresses problems of national significance. Clockwise from upper left: The direct methanol liquid-feed fuel cell, developed for the Advanced Research Projects Agency, provides nonpolluting power. This robot, a JPL–MicroDexterity Systems, Inc., prototype, will enable new microsurgeries. The blue cube is made of silica aerogel, which has applications ranging from cosmic-dust capture to thermal insulation. This serpentine manipulator is designed for inspection in constrained areas. The methanol fuel cell is being assembled for testing.


M. Smart

last year at nine other Federally Funded Research and Development Centers around the nation. JPL's salary freeze was a response to declining budgets and a demonstration of the Laboratory's sensitivity to costs.

Indeed, economy measures have been under way at the Laboratory since 1992, when plans were announced to reduce the work force from that year's level of some 6,400 JPL employees and 1,500 contractors to 5,300 and 1,200, respectively, by 1997 As 1994 ended, the Laboratory was slightly ahead of schedule: The work force stood at some 5,900 Laboratory personnel and 1,300 contractors.

Along with downsizing, JPL made three significant organizational changes in 1994. The first was the creation of a new organization, the Telecommunications and Mission Operations Directorate. Formed out of most of the former Flight Projects Office and the Telecommunications and Data Acquisition Office, the new directorate comprises the Galileo, Magellan, Voyager and Ulysses flight projects, the Deep Space Network and the Multi-mission Operations Systems Office. The consolidation eliminates some overlapping functions of the previous offices and also provides for more efficient management of flight projects and tracking operations.

For example, "uplink" and "downlink" are now seen as complementary parts of the same process — communications between ground stations and spacecraft — and therefore manageable by a more streamlined organization. The Voyager Project, faced with a $3 million reduction in operating funds last year, reorganized from 48 people and 5 teams to 24 people and just 2 simple, functional teams — Uplink and Downlink. Other JPL flight project offices have independently devised solutions to the problem of mission operations costs Galileo, for instance, last year consolidated similar tasks scattered among different operations teams and developed flight software sequences on a "Just-in-Time" basis, reducing staffing and saving $13 million.

The second major organizational change last year was the establishment of another new directorate, Space and Earth Science Programs. Formed out of the former Office of Space Science and Instruments and those flight projects not transferred to Telecommunications and Mission Operations (the TOPEX/Poseidon satellite and the Spaceborne Imaging Radar Project), this directorate has a charter that includes astrophysics and some parts of Mission to Planet Earth, as well as the development of new, small-to-moderate missions to the planets other than Mars.

The development of these small-to-moderate missions was an important consideration in establishing Space and Earth Science Programs. Like other organizations that have instituted systemic change, JPL recognized that well-established ways of doing things, especially if successful, often hinder the introduction of new approaches. To meet the challenge of "faster, better, cheaper" missions and instruments, the Laboratory felt it necessary to create a new environment — hence, Space and Earth Science Programs.

The new directorate oversees the New Millennium effort, SIRTF; WIRE; the Wide Field/Planetary Camera; Pluto Express; the Discovery series of small missions; the Rosetta/Champollion cometary explorer, which is a joint venture between NASA and Centre National d'Études Spatiales; the Seawinds scatterometer; the Microwave Limb Sounder; the Multi-angle Imaging Spectroradiometer, the Advanced Spaceborne Thermal Emission and Reflection Radiometer; the Atmospheric Infrared Sounder/Atmospheric Trace Molecule Spectroscopy; Solar Probe, and space-based interferometry missions.

The third major 1994 organizational change transferred the Cassini Project and the Mars Exploration Program Office from their previous organizations to the Laboratory's Office of the Director This direct-reporting arrangement recognizes the importance of these two efforts to the nation, to NASA and to JPL

Behind the Laboratory's scientific and engineering accomplishments are the administrative and business personnel whose dedicated work makes JPL's scientific and engineering endeavors possible: procurement and contracts officers, documentation writers and editors, software specialists, human resources managers, graphic designers, secretaries, administrative assistants, financial analysts, attorneys, architects, machinists, electrical and electronic technicians, plumbers, carpenters and others

These people are as committed as JPL engineers and scientists to transforming the Laboratory into a better, more efficient organization. For example, in 1994, the Business Operations Directorate looked at the procurement of software and decided the process could be improved. In the past, an order for new software passed through 14 people, required 12 approvals and was entered in 5 separate data banks; on average, it took almost 18 days between placement of an order and receipt of the software

After surveying organizations outside JPL that had already successfully applied Total Quality Management principles to the same problem, Business Operations personnel developed a new, simpler procedure based on the Just-in-Time concept. Now, when commercially available software is ordered, only six people are involved, one approval is necessary, one data bank entry is made and the package is delivered to the employee within two days of the order placement — almost a 90-percent reduction in cycle time. The new system also has the advantage of being nearly paperless. So successful has the new system been that it will be extended to the acquisition of other products, with projected savings of some $5 million a year.

In another demonstration of reengineering, the Contracts Management Office and Financial Management Division merged to become the Contracts and Finance Division. By consolidating functions, this new organization reduced the backlog of unpaid invoices to a few thousand, which can be processed and paid within the required 30-day period.

JPL showed its responsiveness to customers' concerns last year when it improved its management of Government property. A 1993 Government Auditing Office report questioned the use of computers and other equipment by JPL employees off-site, even though neither the Government Auditing Office nor the Laboratory found any evidence of misuse. By the end of 1994, JPL employees had returned 90 percent of the loaned equipment and the remainder was revalidated for off-site use. In a property inventory conducted last year, equipment losses were less than half those of the previous survey period.

Programs to Strengthen the Nation

Although changes are reshaping its work processes and organizational structure, JPL remains a premier space science, engineering and applications laboratory. JPL programs are designed to promote research and technical innovation, and to support national goals in technology commercialization, education and social responsibility.

Through programs of discretionary funding such as the Director's Discretionary Fund, the Laboratory encourages work on innovative and seed research efforts — even those that have not received conventional task-order funding. Proposals eligible for Director's Discretionary Fund monies cover a broad range of sciences and technologies, including advanced optical systems, microinstruments and small payloads. Last year, NASA contributed $3.5 million to the Fund; various reimbursable funds contributed an additional $137,000. The Fund initiated 22 new research tasks, made additional awards to extend the objectives of 4 ongoing tasks and provided assistance to several other efforts.

1994 saw many Laboratory accomplishments in the areas of educational affairs and minority initiatives. For example, the Minority Science and Engineering Initiatives Office — which is part of the JPL Educational Affairs Office — along with the JPL Information Systems and Operations Division and Caltech

Remote Sensing

Instruments developed by JPL capture vital data about Earth and other bodies in the Solar System. Clockwise from upper left: The Airborne Emission Spectrometer measures gases in Earth's troposphere. The Pluto Express cold-gas thrusters (1 of 24 is shown) will control spacecraft orientation during science observations. The Spaceborne Imaging Radar–C (SIR-C) Ground Data Processing System processes radar data for detailed studies of Earth's surface. The Planetary Integrated Camera–Spectrometer will investigate planets and other bodies at ultraviolet, visible and infrared wavelengths.

In recognition of technical innovation, NASA last year awarded JPL employees $151,750, including approximately $53,000 in *NASA Tech Briefs*–related honors and $41,500 under the Software of the Year Awards.

The JPL Technology Affiliates Program gives U.S. companies direct access to the Laboratory's technology base. One-on-one relationships between company employees and JPL personnel facilitate the rapid application of solutions to problems that may be costing firms product-introduction time and money. During 1994, the program grew from 48 to 57 participating companies. JPL has performed nearly 185 individual tasks in the six years since the program's inception.

Through NASA's Small Business Innovation Research Program, JPL last year awarded over 70 contracts, providing small businesses with approximately $15.5 million in resources to develop new dual-use technology for NASA and commercial applications

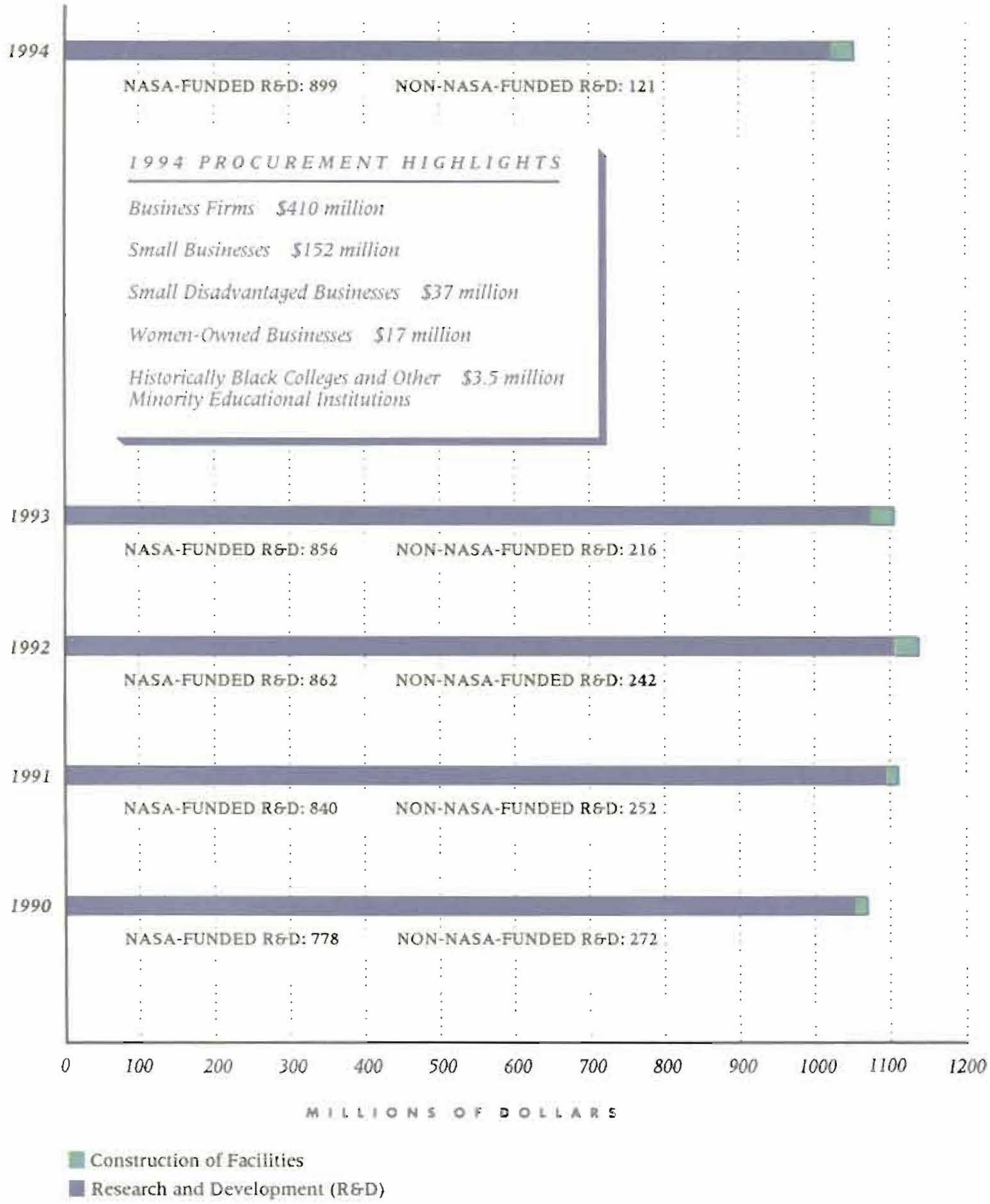
In response to Federal and NASA initiatives, JPL has instituted a program of Technology Cooperation Agreements to pursue dual use of Federally funded technology through cooperative arrangements with U.S. industry. These agreements between JPL and other organizations are mutually beneficial and involve no transfer of funds. In Fiscal Year 1994, JPL signed 16 such agreements, and 11 others are in negotiation

CHALLENGES FOR THE FUTURE

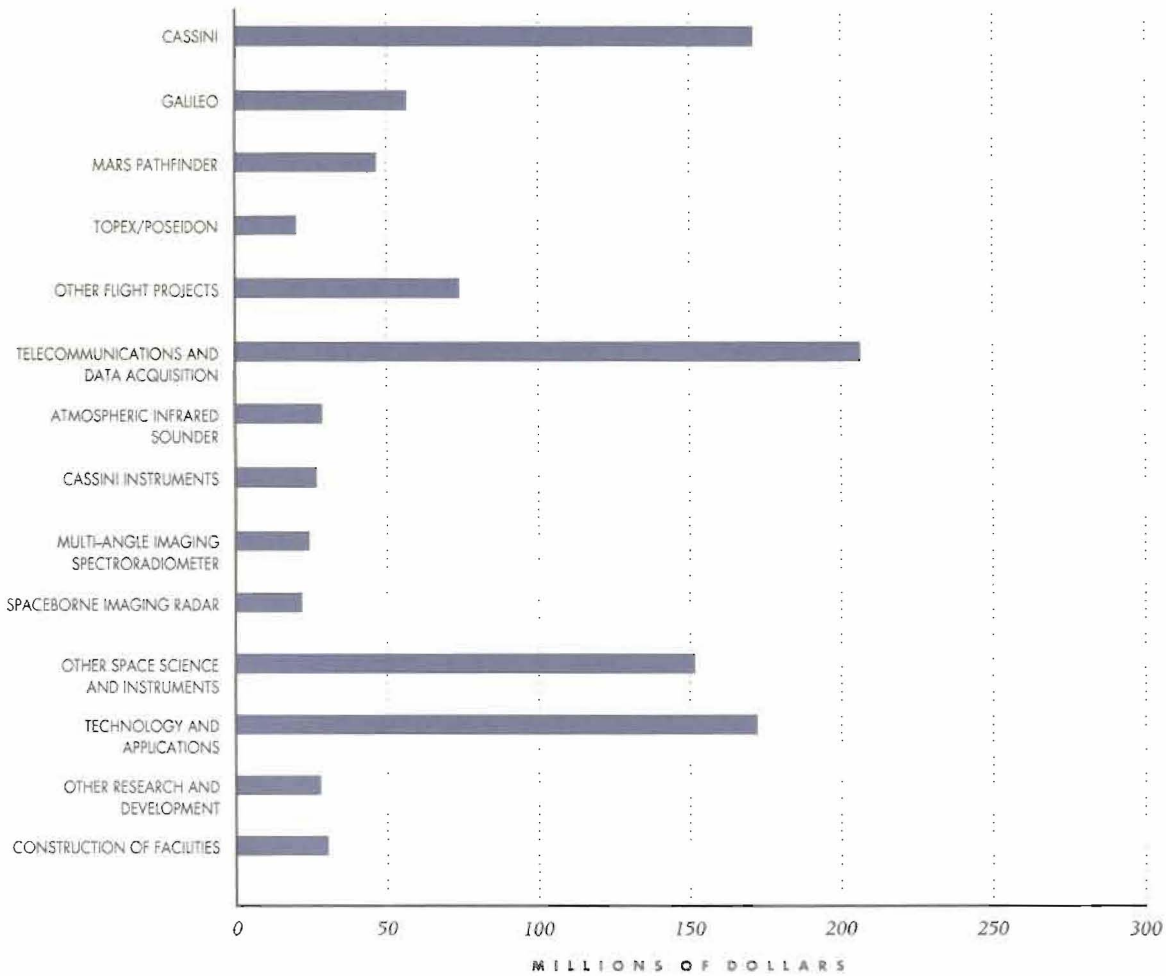
As 1994 drew to a close, the Laboratory had much to be proud of — and, looking ahead, many challenges to face. JPL has begun to change in response to the new national environment, but must continue to be organizationally and programmatically agile enough to deal with further change. Drawing upon the capabilities and dedication of its staff, JPL has faced adversity in the past and surmounted it — and can do so again.

The Laboratory believes that the American people want and will support an ambitious, well-planned and cost-conscious civil space program — and that the projects and tasks to which the gifted people of JPL contribute daily will amply reward society in both the short- and long-term.

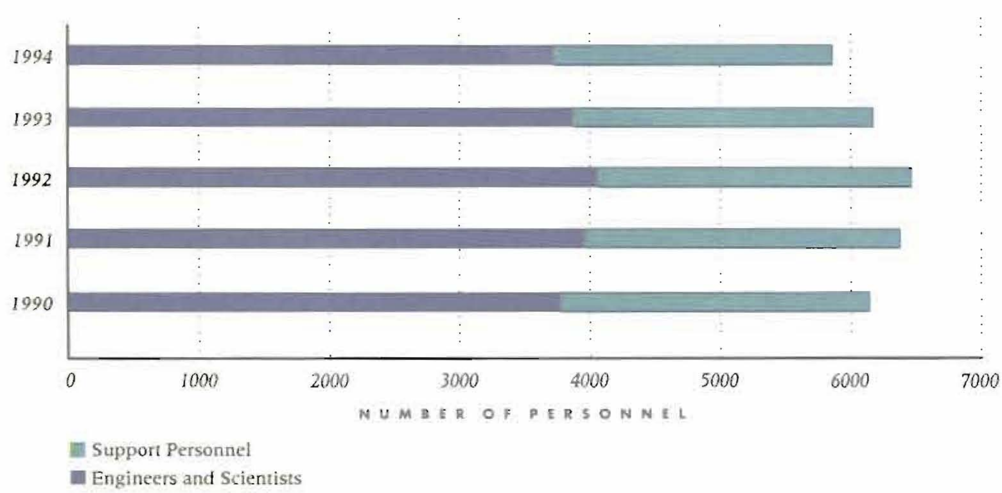
TOTAL COSTS 1990–1994



FISCAL COSTS 1994



TOTAL PERSONNEL 1990-1994



HONORS AND AWARDS

During 1994, a number of special honors, NASA Honor Awards and Laboratory honors were presented to JPL employees in recognition of their exceptional achievements and service. Special honors are awarded to both individuals and groups by a variety of organizations and professional societies. The annual NASA Honor Awards are presented to JPL employees by NASA in recognition of outstanding individual achievements Through a variety of special appointments, Caltech Campus and JPL recognize the accomplishments of individuals and promote the exchange of information in areas of research.

SPECIAL HONORS

Aerospace Laurel Citation 1994, Aviation Week & Space Technology
Galileo flight team, for unique images of comet Shoemaker–Levy 9's collision with Jupiter, and the discovery of Dactyl, a moon orbiting asteroid Ida 243

CNES Medal, Centre National d'Études Spatiales
TOPEX/Poseidon Team. Lee-Lueng Fu, William C Patzert and Charles A. Yamarone, Jr.

Discover Award for Technological Innovation in Aviation and Aerospace, Discover Magazine
Magellan Project, for spacecraft aerobraking maneuvers

Doctor of Engineering Honorus Causa, Valparaiso University
Ronald A Ploszaj

Elected Fellow, American Geophysical Union
Jean O Dickey

Elected Fellow, American Meteorological Society
Moustafa T. Chahine

Elected Fellow, American Physical Society
Santosh K. Srivastava

Elected Fellow, California Academy of Sciences
David Halpern

Elected Fellow, Institute of Electrical and Electronics Engineers
Eni G Njoku

Elected Fellow, Institute of Environmental Sciences
Milena Krasich

Medal of Excellence 1994, Women at Work
Bobbie J Fishman

Most Promising Engineer for 1994, Hispanic Engineer National Achievement Awards Conference
Luis J. Ramirez

Nevada Medal, Desert Research Institute of the Nevada University and Community College System
Charles Elachi

Technology Hall of Fame 1994, National Space Foundation
JPL-developed digital-imaging technologies and excimer laser, which have contributed to the advancement of medical diagnosis and treatment

Outstanding Leadership Medal
- *Charles Elachi*
- *Larry L Simmons*
- *John T Trauger*

Exceptional Achievement Medal
- *Maurice J. Argoud*
- *Willis E. Chapman*
- *Lois L. Cunningham*
- *Esker K Davis*
- *Usama M Fayyad*
- *Lee-Lueng Fu*
- *David B. Gallagher*
- *Ulf E Israelsson*
- *Peter T Lyman*
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- *Donald E. Rockey*
- *Eugene H Trinh*
- *Arthur H Vaughan*

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- *Brian D Hunt*
- *Robert P Korechoff*

Exceptional Service Medal
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- *Teofilo A Almaguer, Jr.*
- *Irving M. Aptaker*
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- *Jewel C Beckert*
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- *Mona M Witkowski*
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- *Sally K. Ride, Space Plasma Physics — California Space Institute, University of California, San Diego, San Diego, California*

- *Carl Wunsch, Oceanography — Massachusetts Institute of Technology, Cambridge, Massachusetts*

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- *Donald K. Yeomans, Solar System Dynamics*

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- *Jordan Ellis*
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- *Barbara A Wilson*

David Morrisroe Professorship in Physics

- *Edward C. Stone*

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